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Memo

Date: December 6, 2004

To: Melvin VanEssendelft

From: Benny Hooda 

Subject: NESHAPs Review of Tritium Production in Helium at the AGS Snake Magnet

As per your request, a NESHAPs compliance review of the white paper titled "An Estimation of Tritium Production in Helium in the AGS Snake Magnet" by E. Lessard and A. Sidi-Yekhlief, dated November 22, 2004 was completed.

The AGS facility is compliant with NESHAPs regulations even though the potential for fugitive losses of tritium exits near the Snake Magnet cryogenic cooling system within the AGS Ring. The potential for tritium production in the liquid helium, used to cool the AGS Snake Magnet, is possible due to secondary and tertiary hadrons scattering and absorption interactions. Only a small quantity (19.5 mCi) of tritium in all three Snake Magnet cooling systems would be produced even with the most conservative assumptions; such as using the highest value of helium cross section, independent spallation cross section above 100 MeV energy and similar cross section for all types of particles/ interactions. The tritium saturation concentration in the AGS Ring will be well below the derived air concentration and consequently the fugitive losses, if any, to the environment will be insignificant.

Based on the conservative criteria that all the tritium produced in the magnet quench was released to the environment, a NESHAPs compliance dose estimate was done using the EPA's CAP88-PC, version 3.0 dose modeling program. The potential effective dose equivalent was well below the 10 mrem/year annual limit as specified in the 40 CFR 61, subpart H, and below the 0.1mrem/ yr. limit, which would require a NESHAPs permit, and continuous monitoring of the emission source. The synopsis report from the dose-modeling program is attached that gives the effective dose equivalent to the maximally exposed individual in the southwest direction as 3.39E-8 mrem/year. An annual confirmatory air sample taken and analyzed for gamma emitting radionuclides in accordance with C-A OPM 9.5.12 also showed that there were no emissions of any other radionuclide from the AGS Ring.

If you have any questions regarding the NESHAPs review, please call Benny Hooda at extension 8107.

BH:car

Distribution: G. Goode R. Karol R. Lee E. Lessard A. Sidi-Yekhlief
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File: EC72ER.04

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Brookhaven National
Laboratory is registered
to the ISO 14001
environmental standard

Clean Air Act Assessment Package - 1988

SYNOPSIS REPORT

Non-Radon Population Assessment

Dec 3, 2004 01:02 pmm

Facility: AGS Ring (Building 913)
Address: Brookhaven National Laboratory
P.O. Box 5000
City: Upton
State: NY Zip: 11973

Source Category: Area
Source Type: Area
Emission Year: 2005

Comments: Tritium Production due to Hadrons interaction
with liquid helium cooling snake magnets at the AG

Effective Dose Equivalent
(mrem/year)

3.39E-08

At This Location: 1600 Meters Southwest

Dataset Name: AGS_2005
Dataset Date: 12/3/2004 1:02:00 PM
Wind File: Z:\CAP88PC2\CAP88PC2\WINDFILES\BNL00.WND
Population File: C:\Program Files\CAP88-PC30\Poplib\BNLB01.PO

MAXIMALLY EXPOSED INDIVIDUAL

Location Of The Individual: 1600 Meters Southwest

Lifetime Fatal Cancer Risk: 1.06E-12

FREQUENCY DISTRIBUTION OF LIFETIME FATAL CANCER RISKS

Risk Range	# of People	Deaths/Year	Deaths/Year	
	# of in This Risk	in This	in This Risk	
Risk Range	People Range or Higher	Risk Range	Range or Higher	
1.0E+00 TO 1.0E-01	0	0	0.00E+00	0.00E+00
1.0E-01 TO 1.0E-02	0	0	0.00E+00	0.00E+00
1.0E-02 TO 1.0E-03	0	0	0.00E+00	0.00E+00
1.0E-03 TO 1.0E-04	0	0	0.00E+00	0.00E+00
1.0E-04 TO 1.0E-05	0	0	0.00E+00	0.00E+00
1.0E-05 TO 1.0E-06	0	0	0.00E+00	0.00E+00
LESS THAN 1.0E-06	5047193	5047193	1.05E-09	1.05E-09

RADIONUCLIDE EMISSIONS DURING THE YEAR 2005

Source

#1 TOTAL

Nuclide	Class	Size	Ci/y	Ci/y
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H-3	V	0.00	2.0E-02	2.0E-02
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SITE INFORMATION

Temperature: 10 degrees C

Precipitation: 110 cm/y

Humidity: 8 g/cu m

Mixing Height: 1000 m

SOURCE INFORMATION

Source Number: 1

Source Height (m): 2.00

Area (sq m): 4.00

Plume Rise

Pasquill Cat: A B C D E F G

Zero: 0.00 0.00 0.00 0.00 0.00 0.00 0.00

AGRICULTURAL DATA

	Vegetable	Milk	Meat
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Fraction Home Produced: 0.000 0.000 0.000

Fraction From Assessment Area: 0.000 0.000 0.000

Fraction Imported: 1.000 1.000 1.000

Beef Cattle Density: 5.83E-02

Milk Cattle Density: 8.56E-02

Land Fraction Cultivated

for Vegetable Crops: 1.88E-02

POPULATION DATA

Distance (m)

Direction	250	850	1600	2250	2750	6300	16800
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N	0	0	0	0	1	4650	0
NNW	0	0	0	0	1	7845	0
NW	0	0	0	0	1	18410	1605
WNW	0	0	0	0	1	42735	59885
W	0	0	0	0	1	50715	137075
WSW	0	0	0	0	1	38830	147520
SW	0	0	97	0	1	22325	66440
SSW	0	0	198	0	1	21875	1120
S	0	0	0	0	1	15900	35
SSE	0	0	0	0	1	22925	0
SE	0	0	0	1	1	9270	16325
ESE	0	0	0	0	1	6375	7080
E	0	0	0	0	1	3095	765
ENE	0	0	0	0	1	2540	0
NE	0	0	0	0	1	3015	0
NNE	0	0	0	0	1	7740	0

Distance (m)

Direction	32000	48000	64000
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N	94925	252075	262180
NNW	211745	108585	54880
NW	137435	124535	104675
WNW	135	217780	131090
W	243225	227190	373120
WSW	360480	427075	778140
SW	3495	0	0
SSW	0	0	0
S	0	0	0
SSE	0	0	0
SE	0	0	0
ESE	0	0	0
E	11765	9250	585
ENE	13175	15220	2300
NE	0	13750	33525
NNE	7125	45010	66315

An Estimation of Tritium Production in Helium in the AGS Snake Magnet

Edward T. Lessard and Ahmed Sidi-Yekhle

November 22, 2004

The AGS beam for part of the FY2005 running period for the nuclear physics program will be high-energy polarized protons directed from the AGS to the AtR transfer line. Some protons will be displaced from the beam within the ASG Ring. Secondary and tertiary hadrons arising from primary beam losses will interact in the helium liquid that cools the AGS Snake Magnet, which is used to maintain the polarization of protons in the beam. The question was raised as to whether AGS beam losses in the vicinity of the Snake Magnet would generate a significant amount of tritium in the liquid helium coolant and if there would be significant tritium gas emission in the helium boil off that would be routinely vented from the AGS Ring. This note presents calculations to address those questions.

The basic assumption is that heat in the Snake Magnet cryogenic cooling system is from ionization in the coolant. This is an overestimate of the amount of ionization in the coolant but it is done this way in order to quantify the maximum possible release of tritium while simplifying the determination of the irradiating fluence. It is noted that operation of the Snake Magnet cooling system outside its anticipated parameter for heat load, 2 watts, is not intended for significant periods of time. There are three cryo-coolers each capable of removing about 1.5 watts for helium at 4.5 °K. It is not possible to run the Snake Magnet if the heat load exceeds the total capacity of the cryo-coolers.

Beginning with a well-established formula for activation:¹

$$P = \sum_{jk} N \int_{E_{jk}}^{E_{kmax}} \sigma_{jk}(E) \varphi_k dE \quad \text{Eq. 1}$$

where P is the constant production rate of tritium atoms in the helium, atoms s^{-1} ,
 N is the number of He atoms in the cooling system,
 σ_{jk} is the cross section for a particle of type k producing a tritium atom via reaction j , cm^2 ,
 φ_k is the fluence rate of particles of type k , particles/ cm^2 s,
 E is the particle energy, with E_{jk} being the threshold energy for reaction j with particle k ,
and E_{kmax} is the maximum energy of particle type k .

This first equation assumes that there is only one radionuclide of interest, tritium. Some other simplifying assumptions are:

- The production of tritium is dominated by hadronic-spallation reactions, without significant contributions from reactions involving leptons, photons or secondary processes. This assumption eliminates the summation over j .
- The cross section for tritium production is essentially the same for all hadrons. This is reasonable given spallation is a strong interaction and eliminates the summation over k , allowing one to use the total number of hadrons to calculate ϕ .
- The spallation cross section is essentially independent of hadron energy above 100 MeV.¹ This assumption eliminates the integration over E .

Using first-order linear kinetics, the number tritium atoms in the coolant at any time is given by:²

$$H = \frac{P(1 - e^{-(\lambda+K)t})}{\lambda + K} \quad \text{Eq. 2}$$

where H is the number of tritium atoms in the helium coolant at any time,
 λ is the decay constant of tritium $= 1.79 \times 10^{-9} \text{ s}^{-1}$,
 K is the boil-off constant for tritium, $0.1 \text{ g s}^{-1}/12300 \text{ g} = 8.13 \times 10^{-6} \text{ s}^{-1}$, and
 t is the irradiation time.

This second equation allows for no decay post shutdown; that is, it gives the tritium atoms at the moment the beam is turned off. The second equation also assumes there are two tritium removal rates at work during irradiation: loss of tritium due to helium boil-off and due to radioactive decay.

Combining the first and second equations with the simplifying assumptions yields:

$$H = \frac{N\sigma\phi(1 - e^{-(\lambda+K)t})}{\lambda + K} \quad \text{Eq. 3}$$

Determination of N is straightforward from Avogadro's number, the mass of liquid helium in the Snake Magnet and the molecular weight of liquid helium:

$$N = \frac{\rho}{M} N_A = (12300 \text{ g} / 4.00 \text{ g mol}^{-1})(6.02 \times 10^{23} \text{ atoms mol}^{-1}) = 1.85 \times 10^{27} \text{ atoms}$$

Deciding on a value for cross section for tritium production from spallation of helium by hadrons is less straightforward and represents most of the uncertainty in this estimate. No measured cross section for the production of tritium through hadronic spallation of helium has been located. However, tritium production cross sections have been compiled for reactions with other targets.³ Plots of cross section versus atomic number show the cross section falling for light elements. Visual inspection places the cross section for helium-4 as low as 5 mb or as high as 30 mb. Additionally, one can calculate 30 mb for the cross section using Reference 4. Thus, 30 mb is chosen here as a reasonable yet conservative estimate for cross section for this specific reaction on helium.

The following assumptions are made in estimating fluence rate, ϕ . The heat load in the liquid helium is reported to be 2 watts under normal operation. This heat load is assumed to be due to secondary and tertiary hadron interactions in helium. The absorbed dose per unit hadron fluence is taken from Reference 5, page 24, as $3.2 \times 10^{-14} \text{ Gy m}^2 \text{ hadron}^{-1}$. The fluence rate into the helium coolant can be calculated from the heat load and absorbed dose per unit hadron fluence as follows:

$$\phi = (2 \text{ watts}/12300 \text{ g})(10^7 \text{ erg/s/watt})(1 \text{ rad}/100 \text{ ergs g}^{-1})(1 \text{ Gy}/100 \text{ rad})/(3.2 \times 10^{-14} \text{ Gy m}^2 \text{ hadron}^{-1})$$

$$\phi = 5.08 \times 10^{12} \text{ hadrons/m}^2 \text{ s}$$

The irradiation time is assumed to be eight weeks, which is $4.84 \times 10^6 \text{ s}$. Using Eq. 3, the number of tritium atoms in the helium coolant at the end of eight weeks is:

$$H = (1.85 \times 10^{27} \text{ atoms})(30 \text{ mb})(10^{-27} \text{ cm}^2/\text{mb})(5.08 \times 10^{12} \text{ hadrons/m}^2 \text{ s})(1 \text{ m}^2/10^4 \text{ cm}^2) \\ (1 - e^{-(0.00000000179/\text{s} + 0.00000813/\text{s})(4,840,000 \text{ s})})/(1.79 \times 10^{-9} \text{ s}^{-1} + 8.13 \times 10^{-6} \text{ s}^{-1})$$

$$H = 3.47 \times 10^{15} \text{ tritium atoms}$$

The tritium activity, A , in the helium coolant is given by:

$$A = H \lambda$$

$$A = (3.47 \times 10^{15} \text{ tritium atoms})(1.79 \times 10^{-9} \text{ s}^{-1})$$

$$A = 1.68 \times 10^8 \text{ pCi}$$

$$A = 6.22 \times 10^6 \text{ Bq}$$

The tritium release rate, Q , from boil-off is given by:

$$Q = HK$$

$$Q = (3.47 \times 10^{15} \text{ tritium atoms})(8.13 \times 10^{-6} \text{ s}^{-1})$$

$$Q = 2.82 \times 10^{10} \text{ atoms/s}$$

$$Q = 1360 \text{ pCi/s}$$

$$Q = 50.3 \text{ Bq/s}$$

The Derived Air Concentration (DAC) for the Annual Limit on Intake of a radionuclide is that concentration which will deliver the annual limit of dose equivalent to a worker who continuously occupies an area at one DAC for one working year (2000 hours). In the case

of tritium, the DAC is 8×10^5 Bq/ml.⁶ The tritium in the Snake Magnet is mixed with 12300 g of liquid helium, which is 9.8×10^4 cc of liquid, and the liquid to gas expansion ratio is 768 at 300 °K. The resulting airborne tritium concentration is at least seven orders of magnitude less than the DAC, and it would exist temporarily in the vicinity of the Snake Magnet after a loss of coolant event inside the AGS Ring. Therefore, no significant radiological hazard to a worker exists.

From the standpoint of environmental protection, one considers the total amount of tritium released from a magnet quench and assumes that all of it is vented to the outside. The other environmental consideration is routine emission of tritium with the helium boil off for eight weeks of operation. Using EPA's CAP88 Code with BNL site parameters, the maximum dose to an individual off site would be 1.8×10^{-8} mrem for the quench event and 6.8×10^{-7} mrem during the eight week program from routine tritium emissions.⁷ Even if the cryo-coolers were run at full capacity of 4.5 watts, rather than at the expected routine level of 2 watts, off-site doses would be well below the 0.1 mrem per year trigger for monitoring requirements prescribed by EPA in 40 CFR 61.

References

1. H. W. Patterson and R. H. Thomas, Accelerator Health Physics, p. 519, Academic Press, New York (1973)
2. Skrable K., French C., Chabot G., Major A., A General Equation For The Kinetics Of Linear First Order Phenomena And Suggested Applications, Health Phys. 27(1):155-7, (1974).
3. A. Konobeyev and A. Korovin, Nuclear Instruments And Methods, V 82, p.103, (1993)
4. M. Barbier, Induced Radioactivity, North-Holland Publishing Company, Amsterdam and London (1969)
5. A. H. Sullivan, A Guide to Radiation and Radioactivity Levels Near High Energy Particle Accelerators, Nuclear Technology Publishing, Kent, England (1992)
6. U. S. Department of Energy, *Occupational Radiation Protection; Final Rule*, 10 CFR 835, Appendix A, (1993)
7. U. S. Environmental Protection Agency, CAP88-PC provides a framework for developing inputs to perform dose and risk assessments in a Windows environment for the purpose of demonstrating compliance with 40 CFR 61.93(a). For questions about this program, please contact:
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